8 GeV Beam Absorber for Beam Line Commissioning

C-Winfrey & C-Bhat
July 31, 1996

In the commissioning phase of the 8 GeV beam line a temporary beam absorber is under consideration. Presented in this report is the proposed design of the beam absorber. During the Main Injector era the 8 GeV proton beam from the Fermilab Booster will be transported to the Main Injector through the newly built 8 GeV beam line. This beam line is about 757.9 meters long. A schematic layout of the beam line is shown in Fig.1. Originally this beam line was planned to be built by using conventional electromagnets (and power supplies) of the Main Ring. Very recently a decision was made to build the beam line with permanent magnets with construction scheduled to be completed by February 1997, a year ahead of the scheduled completion date of the Main Injector. The beam line will also be commissioned well before the long shut down of the accelerator complex (presently scheduled during February 1998). The early commissioning of the 8 GeV beam line is most crucial for the Fermilab 8 GeV anti-proton recycler ring project, since the permanent magnets to be used in the 8 GeV beam line are similar to the ones in the recycler ring.

The beam absorber will only be in operation for a short time. During the commissioning of the 8 GeV beam line, accelerator and construction personnel will have access to downstream regions of the 8 GeV beam line and the Main Injector Tunnel. Although the beam absorber will be used for only a short time, worker safety is still a priority. Since accelerator personnel might be working in the vicinity of the downstream region of the beam absorber for extended lengths of time when the beam absorber is in use, it is mandatory to meet either no-occupancy limit (<0.025 mrem/hr) or no-occupancy limit (<0.25 mrem/hr) with signs reading "**Caution-Controlled Area**". The table shown below lists various parameters and assumptions used in the beam absorber design and its shielding requirements.

Table I.

Assumptions & Shielding Requirements

Beam Energy	8 GeV
Beam Intensity	3.6×10^{13} p/hr *
Required Radiation Level	0.25 mrem/hr (with precaution) [Ref. 1 Table 2-5]
Density of soil (concrete)	2.24 g/cm^3
Density of Iron	7.86 g/cm^3
Conversion Factor	10^{-5} rem/star/cc [Ref. 1 Table 13-1]

* (12 booster batch/min) X (5×10^{11} p/batch) x 60 min/hr

The beam absorber is going to be built in the 8 GeV Beam line which is at an elevation of 218.04 m (715.5 ft), while the average surface elevation is about 227.38 m (746 ft). This provides about 7.62 m (25 ft) of soil radially which is slightly more than recommended radial shielding of 7.47 m (24.5 ft) [2] for the 8 GeV beam line. Therefore, for this beam absorber, shielding only in the longitudinal (in the direction of beam) direction is needed.

A. Beam Absorber Design I.

In this design the beam absorber is basically an iron slab surrounded on three sides with concrete. The fourth side is exposed to the oncoming beam. A schematic view of the design is included here in Fig. 2. The possible location of the beam absorber is indicated in Fig. 1.

To determine the longitudinal extent of the shielding in the tunnel for the beam absorber, Monte Carlo calculations were carried out using the computer code CASIM [3]. Cylindrical geometry was used in the calculations. Properties of the soil, concrete, and iron used in the calculations are given in Table I.

The CASIM calculations are limited by statistics in regard to the radiation level downstream of the steel block but far away from the point of primary beam interaction. Hence to determine the attenuation of the radiation level in the soil, a separate Monte Carlo calculation (similar to ref. 2) at 8 GeV was performed. The results of these calculations, shown in Fig. 3, show that an average shielding of 1.5 m of soil is necessary to reduce the radiation level by one order of magnitude in the longitudinal direction.

Table II

8 GeV Beam Line Temporary Beam Absorber

	Target Scenario (iron block) (m)	Radiation Level (mrem/hr)	Concrete(Soil) Thickness (m)
1.	0.305X0.305X2.74	0.25	9.46
	(1'X1'X9') Fig. 4(a)	2.5	8.06
		10.0	7.06
2.	0.61X0.61X2.74	0.25	8.86
	(2'X2'X9')Fig. 4(b)	2.5	7.46
		10.0	6.26
3.	1.22X1.22X2.74	0.25	7.66
	(4'X4'X9')Fig. 4(c)	2.5	6.36
		10.0	5.66
4.	1.22X1.22X3.35	0.25	6.75
	(4'X4'X11')Fig. 4(d)	2.5	5.55
		10.0	4.75
5.	.0.61X0.61X1.52	0.25	7.05
	additional	2.5	5.85
	1.22X1.22X1.82	10.0	4.85
	block added		
	Fig. 4(e)		

@ 0.25 mrem/hr, radiation/p @ 8 GeV is 6.9 X 10-16
@ 2.5 mrem/hr, radiation/p @ 8 GeV is 6.9 X 10-15
@ 10.0 mrem/hr, radiation/p @ 8 GeV is 2.8 X 10-14

The results of the calculations for four different geometries of the beam absorber considered here in combination with results from Fig. 3 are presented in figures 4(a) to 4(e). Cases for 0.305 m X 0.305 m X 2.74 m , 0.61 m X 0.61 m X 2.74 m , 1.22 m X 1.22 m X 2.74 m, and a mixed configuration of steel with soil are reported. The final contours of equal radiation dose are shown in these figures. A conversion factor of 10^{-5} rem/star per cubic centimeter [1] was used to determine the radiation level from the star density calculations of CASIM. These contour plots were instrumental in determining the concrete thicknesses needed to achieve a certain radiation level. Using the beam intensity given in Table I, the shielding thickness was determined. The estimated concrete thicknesses downstream of the iron block are listed in Table II.

As one can see from Table II, abiding by the rules and regulations of the Fermilab Radiological Control manual [1] for a controlled area dose rate of 0.25 mrem/hr, the concrete thickness has to be 9.46 m for an iron target of dimensions 0.305 m X 0.305 m X 2.74 m and 8.86 m for an iron target of dimensions 0.61 m X 0.61 m X 2.74 m.

B. Beam Absorber Design II.

A new design of the beam absorber suggested by Phil Martin is studied here. In this design the 30.5 cm X 30.5 cm X 229 cm iron slab is embedded in a 137 cm X 137 cm X 4.5 m concrete block and is situated at location 840. In the presence of the beam the entire 8 GeV beam line will be secured with the help of an interlocked gate at location 850 which is at about 152 m (500 ft) downstream of the beam absorber. Sectional and plan views of this design appear in Fig. 5. With this design there will be about 1.5 m of clearance on one side of the beam absorber. Hence, when the beam absorber is not in use accelerator personnel can access this area.

The radiation levels at different points in the beam line tunnel downstream of the beam absorber are determined in two steps. First, the radiation source strength is determined by using CASIM. Secondly, the attenuation of the radiation level is estimated by using the computer code EXIT2A (Craig Moore). Using the program EXIT2A in this situation is not fully justified except for the fact that the beam line has a bend of about 15° from the 840 location to the 850 and the secondary radiation produced at the beam absorber has to at least scatter once before reaching the 850 location.

Table III

EXIT2A Inputs & Radiation Level

Source Strength Radiation of the Beam Absorber = 10^{-12} rad/incident proton at 8 GeV. Tunnel Width = 3.05 m (10'), Height = 2.44 m (8').

Beam intensity limit is determined assuming 0.25 mrem/hr (no occupancy limit, with signs reading "Caution-Controlled Area")

Leg Dimension	Attenuation	Radiation Level (rad/p @ 8 GeV)	Beam Intensity
R = 1'			
L1 = 350'	0.51×10^{-3}		
L2 = 150'	0.36×10^{-4}		
	1.84×10^{-8} (total attenuation)	1.8×10^{-20}	$1.4 \times 10^{+16}$/hr
R = 350'	8×10^{-6}		
L1 = 150'	0.3×10^{-2}		
	2.4×10^{-8} (total attenuation)	2.4×10^{-20}	$1.0 \times 10^{+16}$/hr

Figure 6 gives results of the CASIM calculations for a geometry shown in Fig. 5. Thus, the highest radiation level at the surface of the beam absorber during its use is about 10^{-12} rem/p @ 8 GeV, which is used as the strength of the primary radiation level for EXIT2A calculations.

A schematic view of this region is given in Fig. 7. Table III summarizes the results of EXIT2A calculations. Two scenarios listing the dimensions of the legs are shown in the first column. The second column lists the calculated attenuation factor of radiation in each leg. The results of the radiation level per 8 GeV proton loss at the beam absorber and the allowed protons/hr, if it is assumed the radiation level is less than or equal to 0.25 mrem/hr, are listed in column 3 and 4 respectively.

C. Radioactivity of the Beam Absorber

Induced radioactivity of the beam absorber is one of the important issue to be addressed during designing the temporary beam absorber. This helps to determine: a) how long will it take for the beam absorber to cool down to a safe limit after each study time so accelerator personnel can work near the beam absorber; and b) precautions to be taken in disposing of it.

The model described in reference [1] was used to determine the induced radioactivity of the beam absorber. The dose rate is given by :

$$D = [\Omega/4*\pi] * \Phi * \text{ danger parameter.}$$

D is the dose rate and Ω is the solid angle. The hadron flux, Φ, is given by;

$$\Phi = \text{conversion factor} * \text{stars/cc} * \text{beam intensity.}$$

A conversion factor of 75 for iron and 275 for concrete are taken from reference [4]. The star densities are taken from Fig. 6. The geometry factor, $[\Omega/4*\pi]$ = 1/2 at contact. The beam intensity = $1X10^{11}$ p/sec.

In the present discussion the following two cases were considered. a) irradiation time, T_i = 1 days and cooling time, T_c = 1 hour; b) T_i = 30 days and T_c = 1 hour. The danger parameters as a function of T_i and T_c were as follows: a) in the case of Fe; T_i = 1 day, T_c = 1 hr, d = 1.5 X 10^{-8} rad/hr and T_i = 30 days, T_c = 1 hr, d = 3 X 10^{-8} rad/hr; b) In the case of concrete T_i = 1 day, Tc = 1 hr, d = 8 X 10^{-9} rad/hr and T_i = 30 days, T_c = 1 hr, and d = 10^{-8} rad/hr. The estimated induced activities are give in Table IV.

Table IVa.

Description	#of stars/cc	D (dose rate on contact) rad/hr Ti = 1 day & Tc = 1 hr	 Ti = 30 days & Tc = 1 hr
Front			
Steel Target	10^{-3}	56.25	112.5
Concrete A	10^{-6}	0.11	0.14
Concrete B	0.5 X 10^{-7}	0.0055	0.006875
Side			
Concrete C	10^{-7}	0.011	0.01375
Back			
Concrete D	$<10^{-7}$	<0.011	<0.01375

Table IVb.

	Dose Rate (rad/hr) On Contact			
	Ti=1 day & Tc=1 day	Ti=1 day & Tc=7 days	Ti=30 days & Tc=1 day	Ti=30 days & Tc=7 days
Fe (Front)	16.875	3.75	93.75	37.5
Concrete				
A	1.4 X 10^{-2}	5.5 X 10-4	2.75 X 10-2	1.4 X 10 -3
B	6.9 X 10^{-4}	2.8 X 10-5	1.4 X 10-3	6.9 X 10-5
C	1.4 X 10^{-3}	5.5 X 10-5	2.8 X 10-3	1.4 X 10-4
D	<1.4 X 10^{-3}	<5.5 X 10-5	<2.8 X 10-3	<1.4 X 10-4

D. Summary

In this report, presented are two possible designs for the internal beam absorber which can be used during the 8 GeV beam line commissioning. With design I less radiological control is needed as compared to design II. Table II. clearly indicates for a larger iron target less concrete (soil) is needed for a certain radiation level and vice-versa. The actual combination used will depend on the radiation level desired and the amount of money that is willing to be spent on the temporary beam absorber. If the amount of iron to be used is not an issue then either beam absorber scenario 4 or 5 has an advantage over all the other four cases discussed; the absorber length can be considerably reduced by about 2 meters as compared with case 1.

Design II is more desirable as far as the Main Injector project is concerned. From Table III it is evident that the amount of beam that can be absorbered is a factor of 250 higher than design I. However there are many assumptions in the estimation of radiation level. For example, it has been assumed that EXIT2A (which was not appropriate to use) can be used in this design. If this design is chosen, it is urged that an interlock detector be established at location 850. Accelerator personnel access to the 8 GeV Beam Line has to be prohibited during use of the beam absorber. Radiation levels should be monitored to ensure the radiation levels stay well below the acceptable limits in the Main Injector Tunnel. In any case the concrete block, downstream and surrounding the iron block has to be hand stacked without any voids, to avoid any additional leakage of the radiation longitudinally.

The radiation isssues of the beam absorber and its vicinity discussed here pertain to that arising from hadrons only. Radiation arising from muons have been omitted for both of these designs I and II mainly because the energy of the primary beam is only 8 GeV.

Authors would like to thank P. Martin and A. Van Ginneken for useful discussions.

References

[1] Fermilab Radiological Control Manual, table 13-1.

[2] Fermilab Main Injector Preliminary Safety Analysis Report-(1992 page 45).

[3] Ginneken, A. Van, "CASIM: Program To Simulate Transport of Hadronic Cascades in Bulk Matter", 272 1100.050.

[4] Ginneken, A. Van, "High Energy Particle Interactions in large Targets" page 83, VOL. 1.

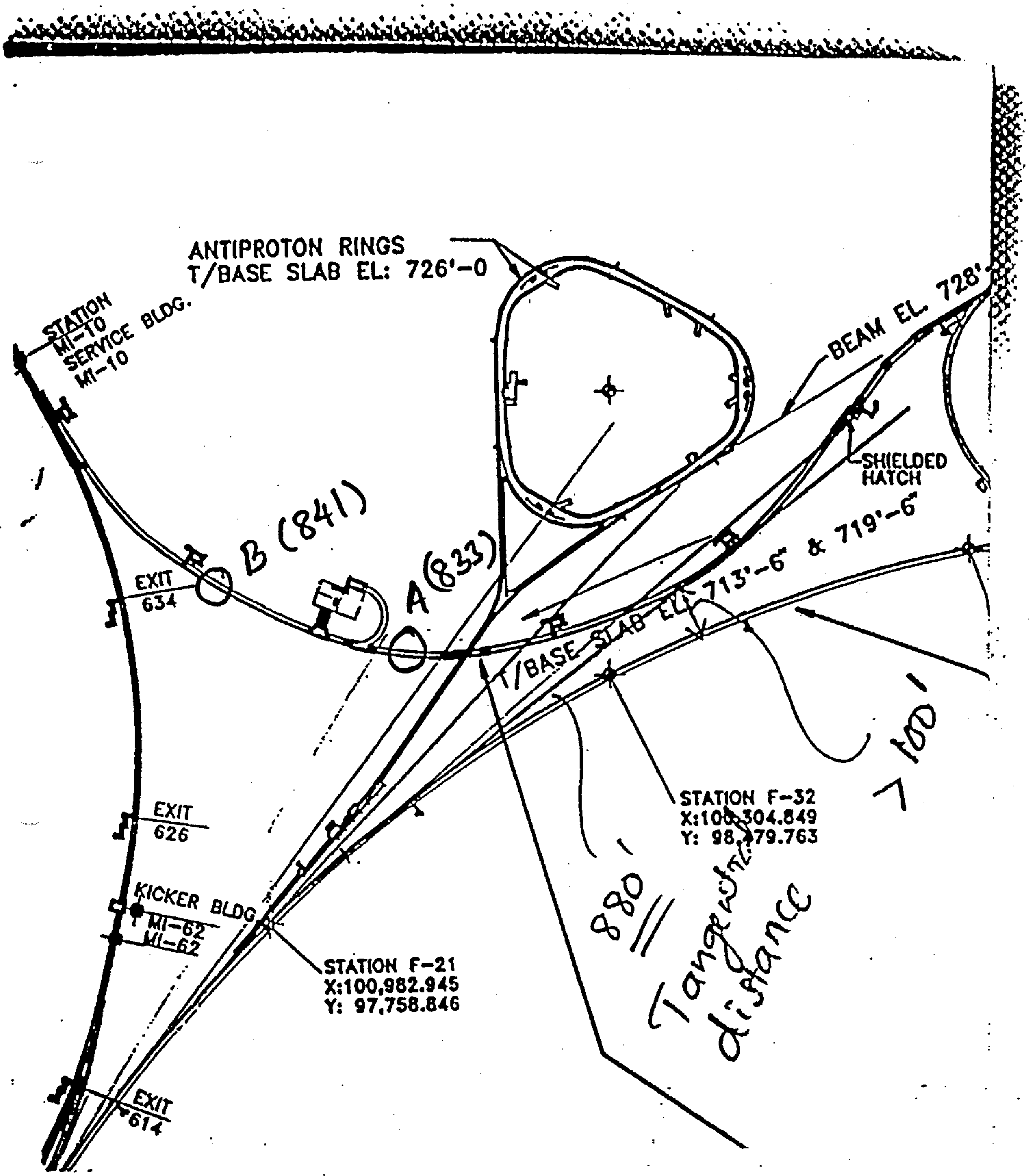


Fig. 1. 8 GeV Beam line. Possible locations of the temporary beam absorber are indicated by circles.

8 GeV Beam Absorber Design - I

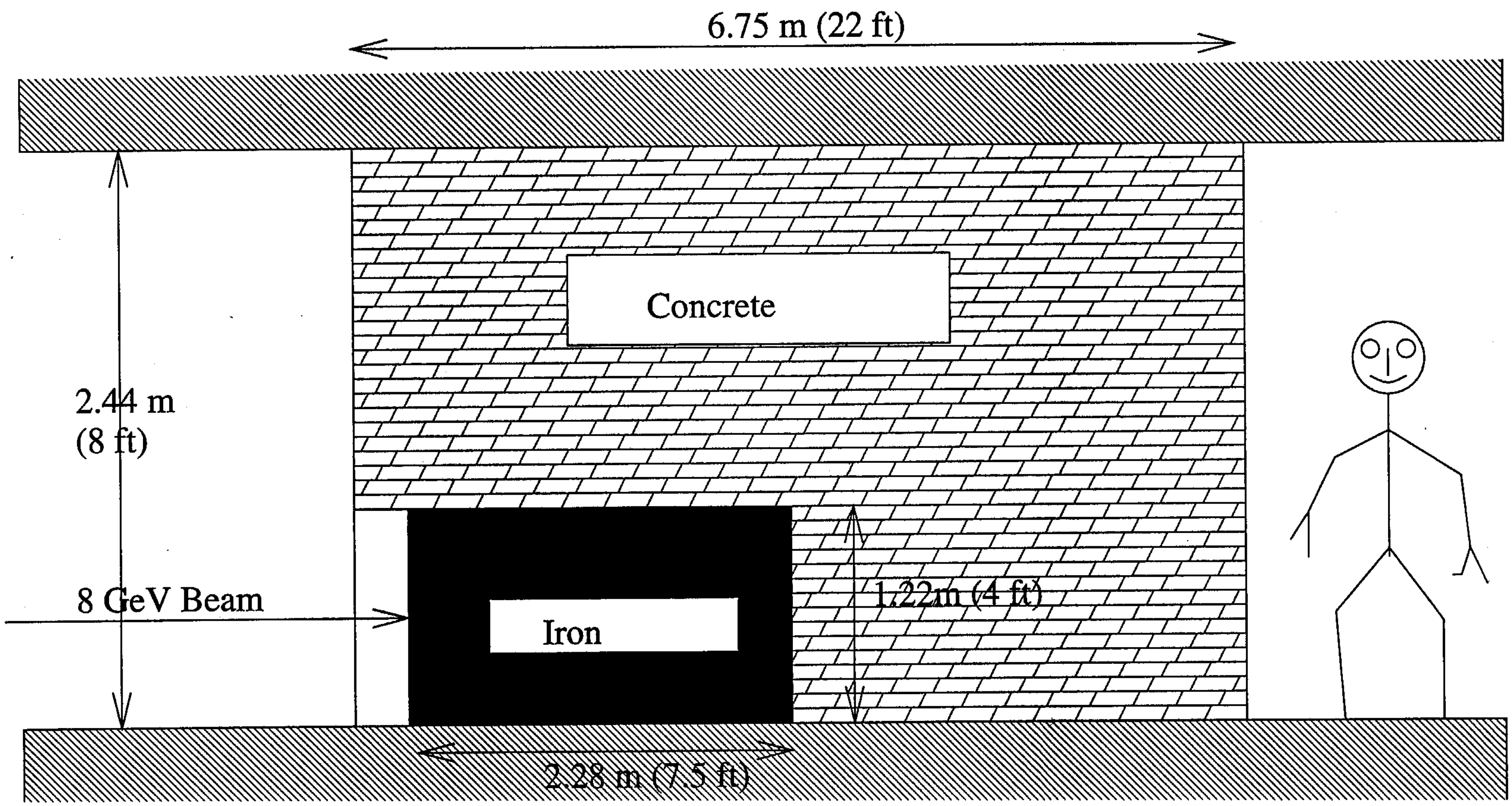
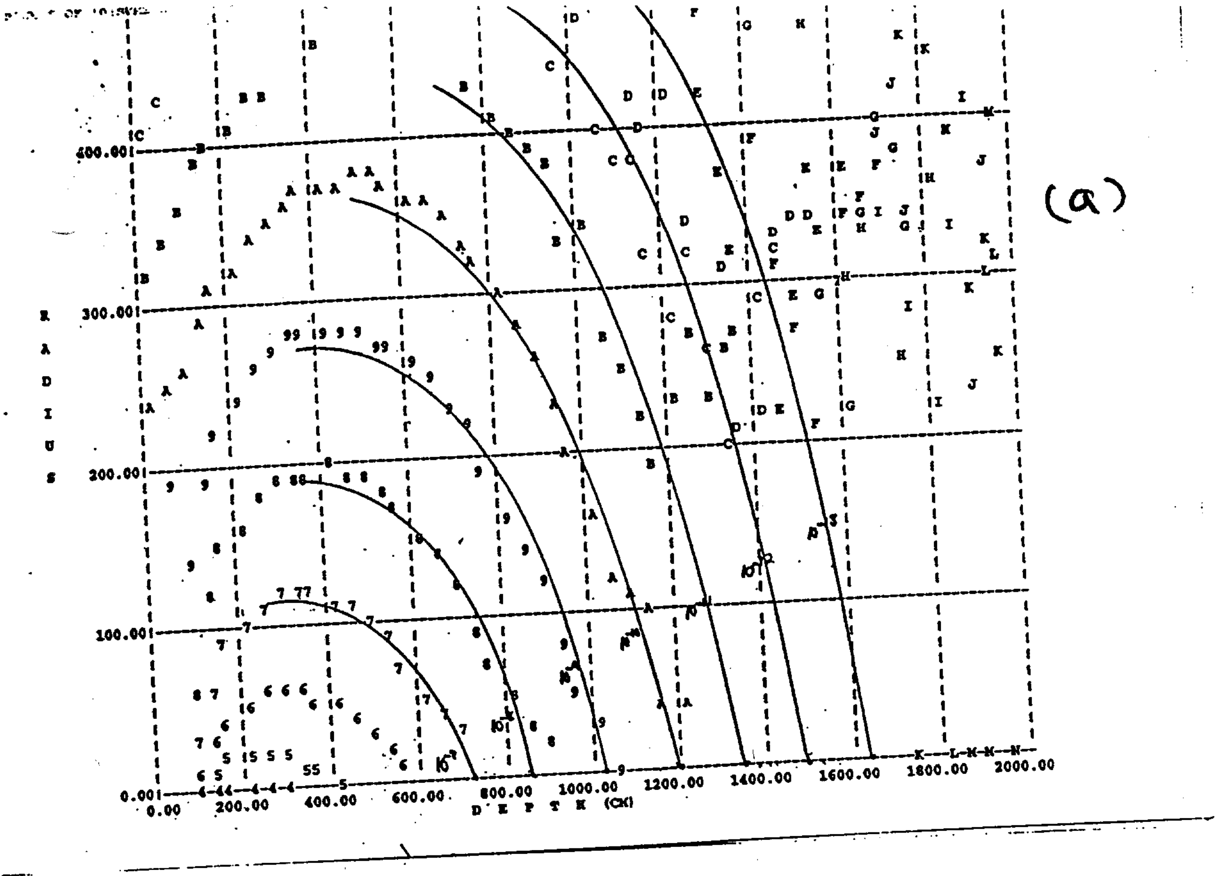
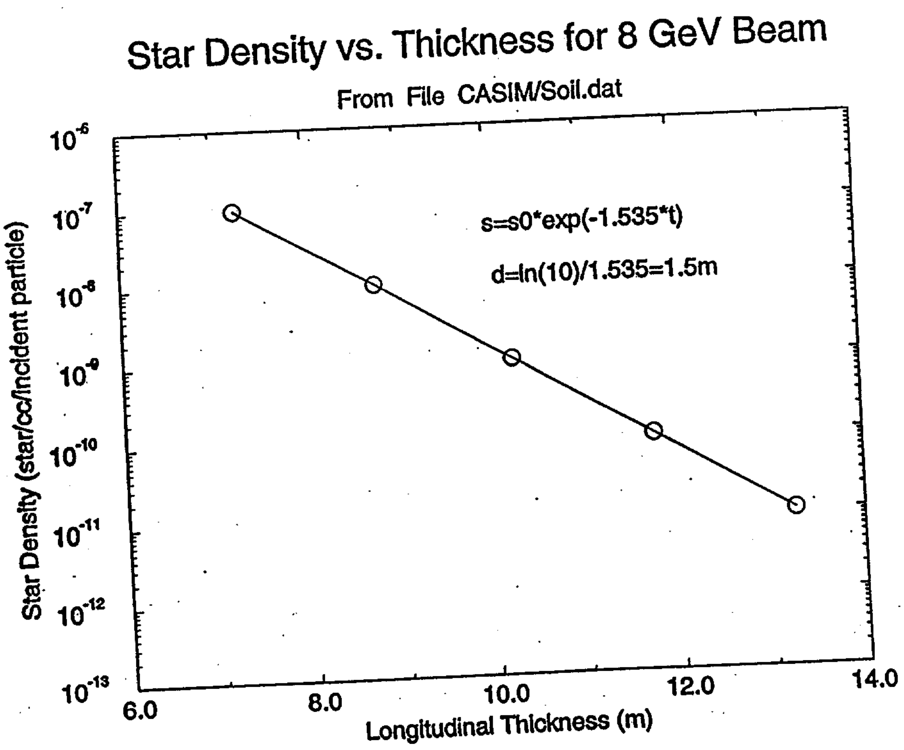


Fig. 2. A schematic view of the 8 GeV temporary Beam Absorber in the beam line tunnel (design I)



(a)



(b)

Fig. 3. Monte Carlo calculation for interactions of 8 GeV protons in soil using computer code CASIM [3]. a) The contours of equal radiation dose. The radiation dose (rem/p @ 8 GeV) are indicated. b) Star densities in soil versus longitudinal soil thicksness.

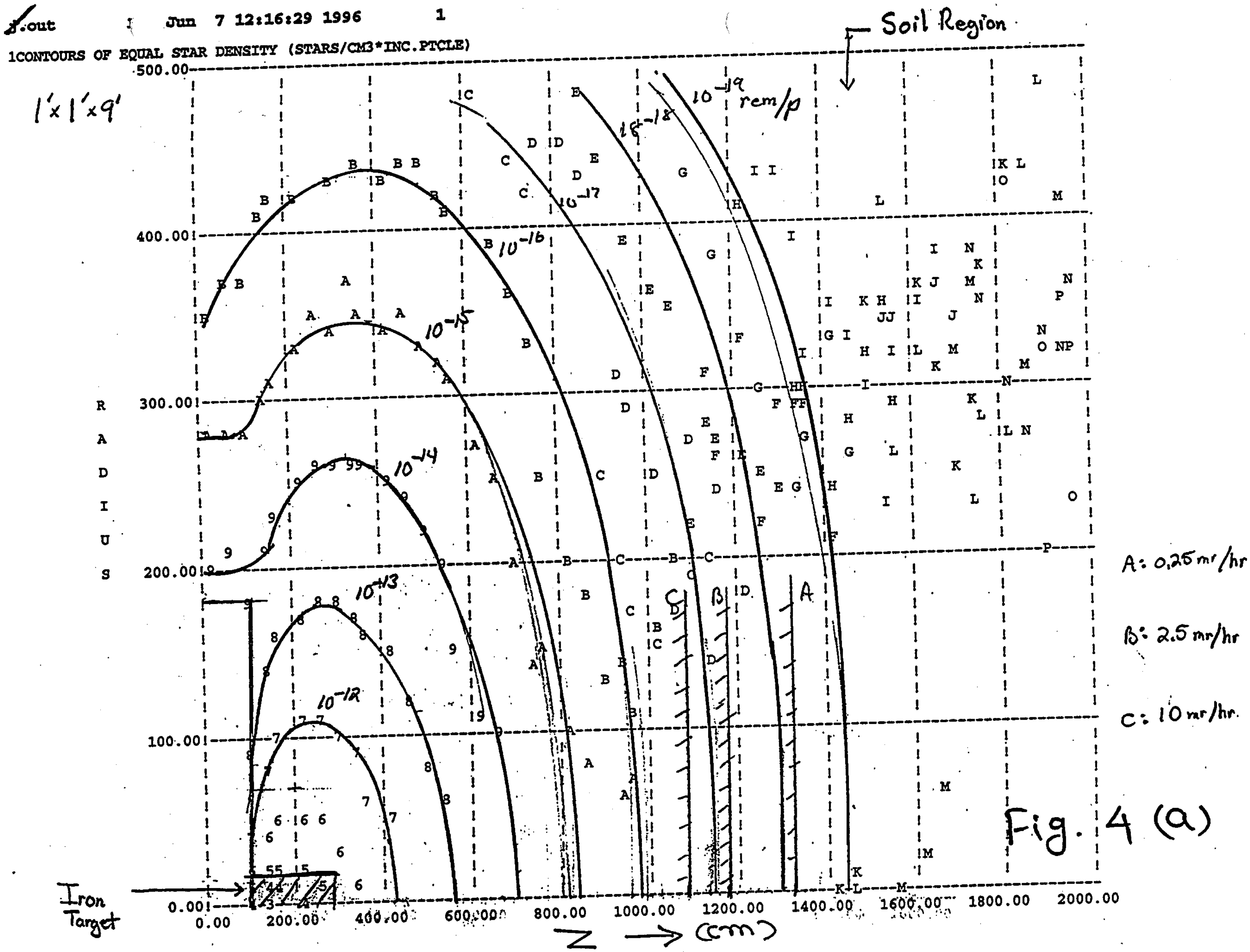


Fig. 4. Monte Carlo calculation using computer code CASIM [3] for interactions of 8 GeV protons with beam dump design I. The details of each figure from 4(a) - 4(e) are indicated on the figures.

Fri Jun 7 08:53:24 1996 2

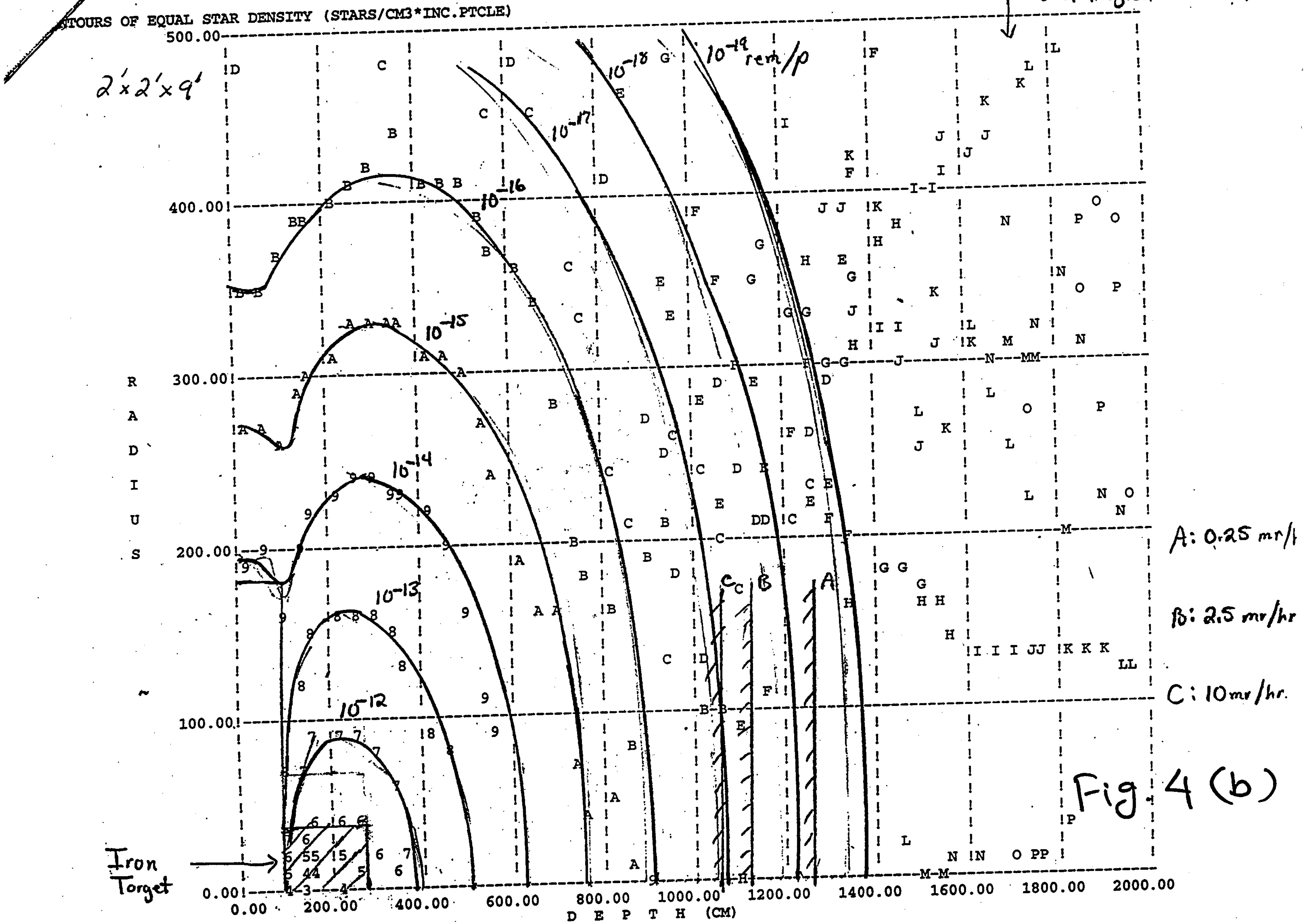


Fig. 4 (b)

sim_68r27.4_partial.out Wed Jul 3 09:58:47 1996

1CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)

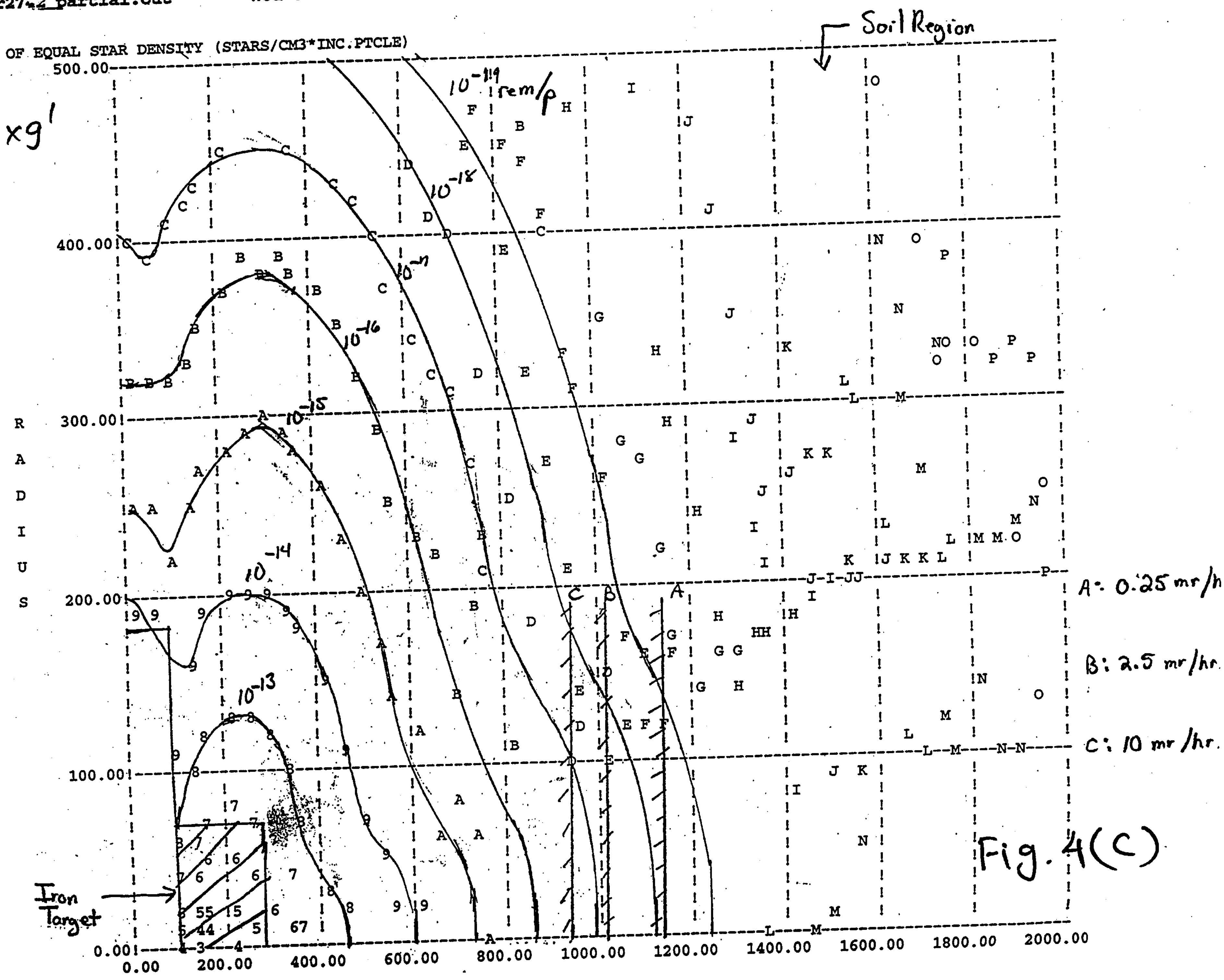


Fig. 4(c)

sim_68r552_partial.out Mon Jun 24 07:25:55 1996

1CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)

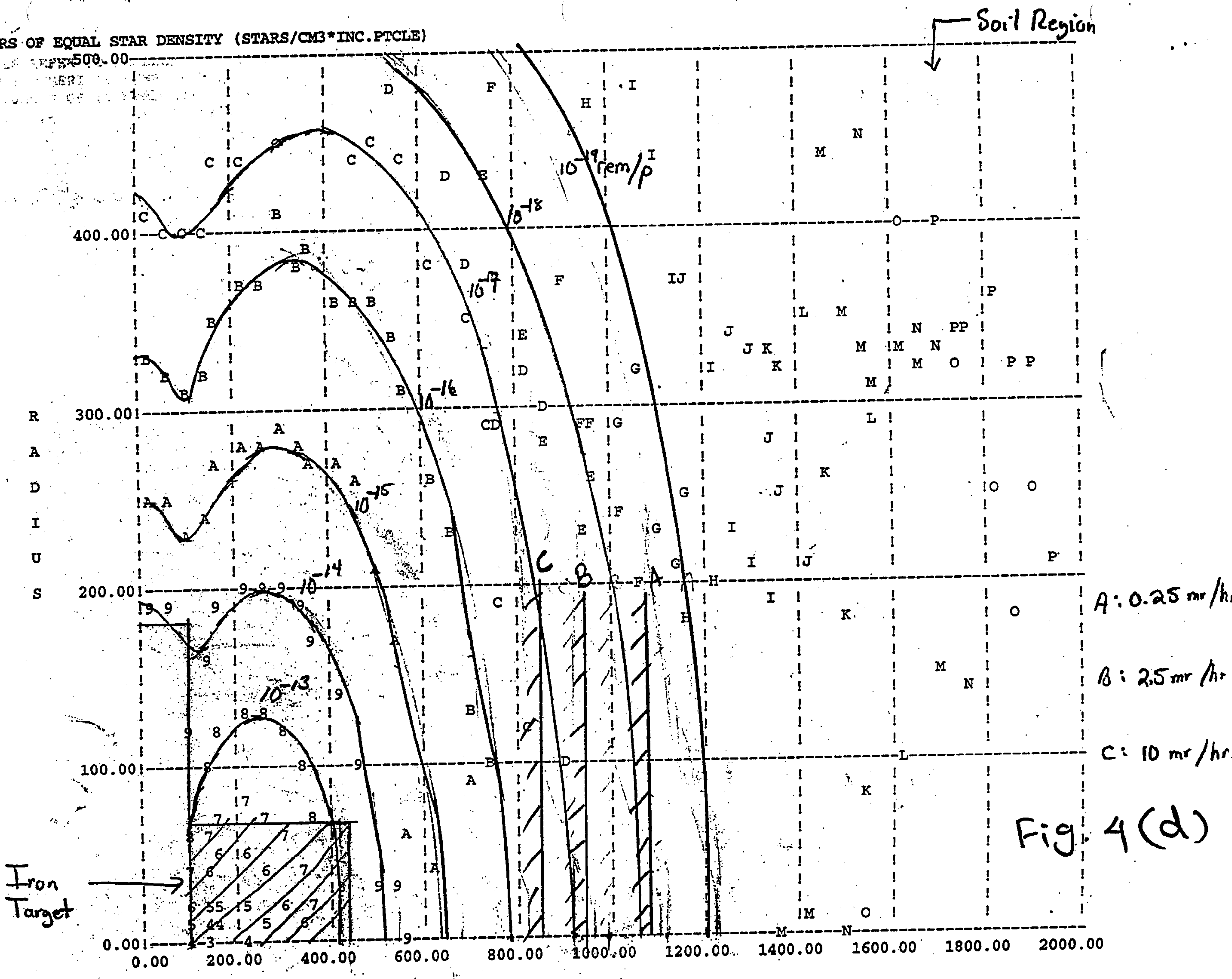


Fig. 4(d)

1CONTOURS OF EQUAL STAR DENSITY (STARS/CM3*INC.PTCLE)

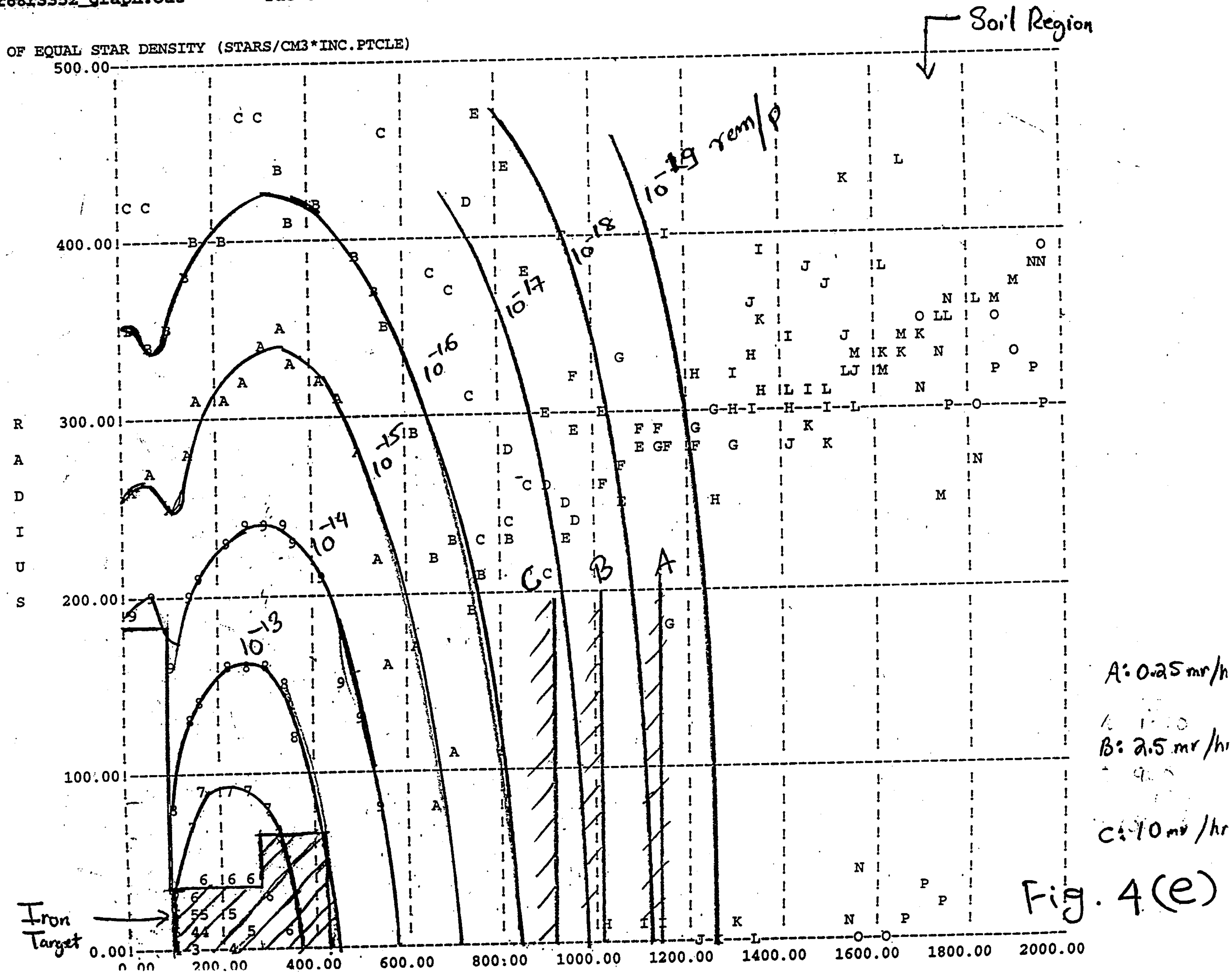
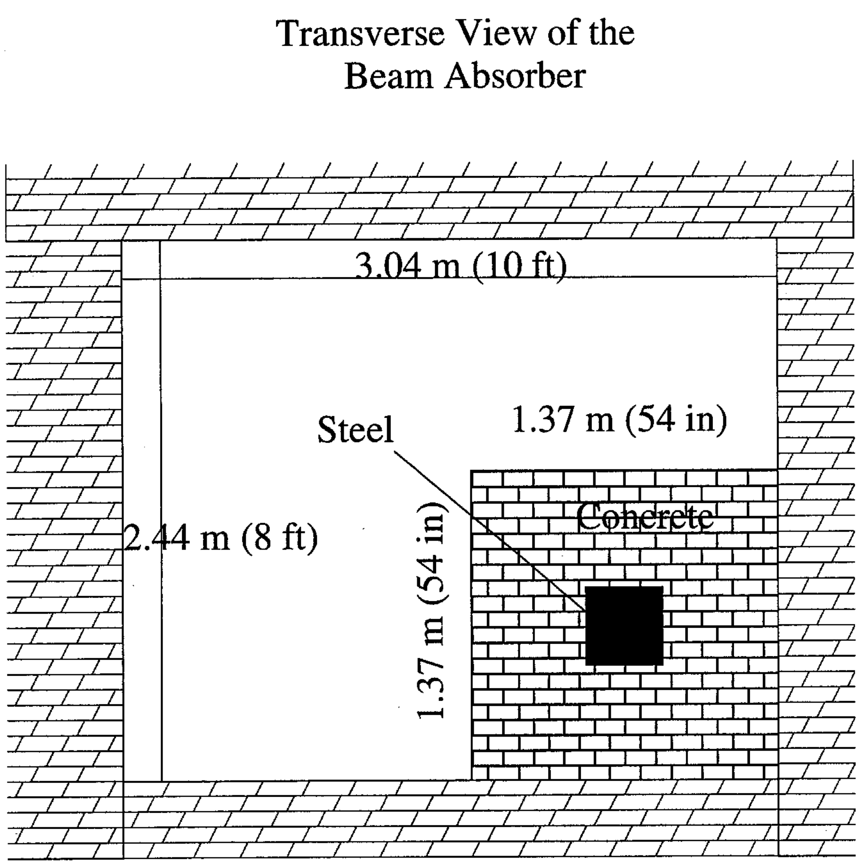


Fig. 4(e)

8 GeV Beam Absorber, Desigh - II



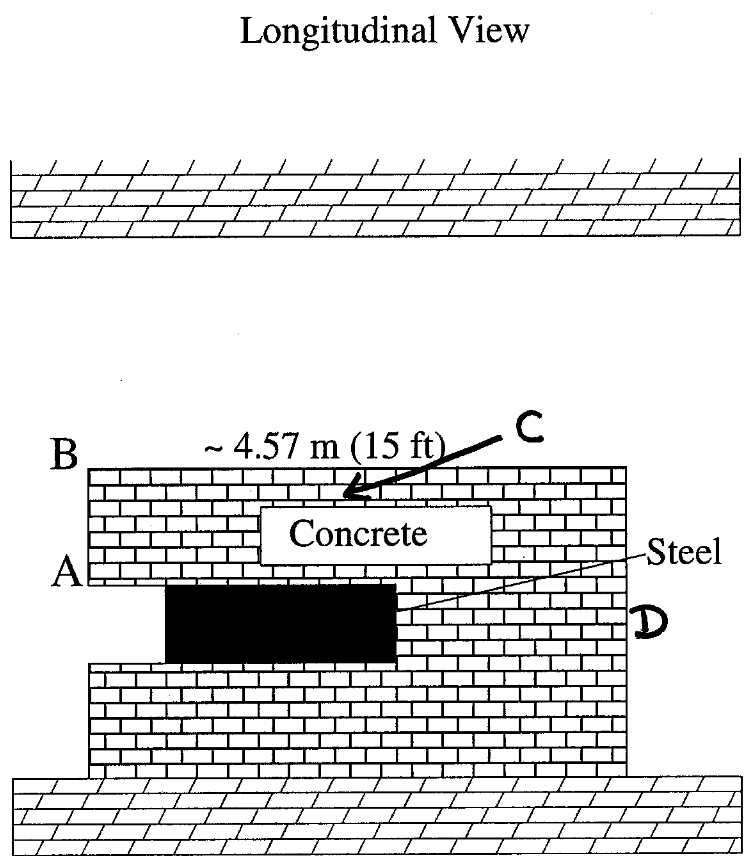


Fig. 5. A schematic view of the 8 GeV beam absorber in the beam line tunnel (design II)

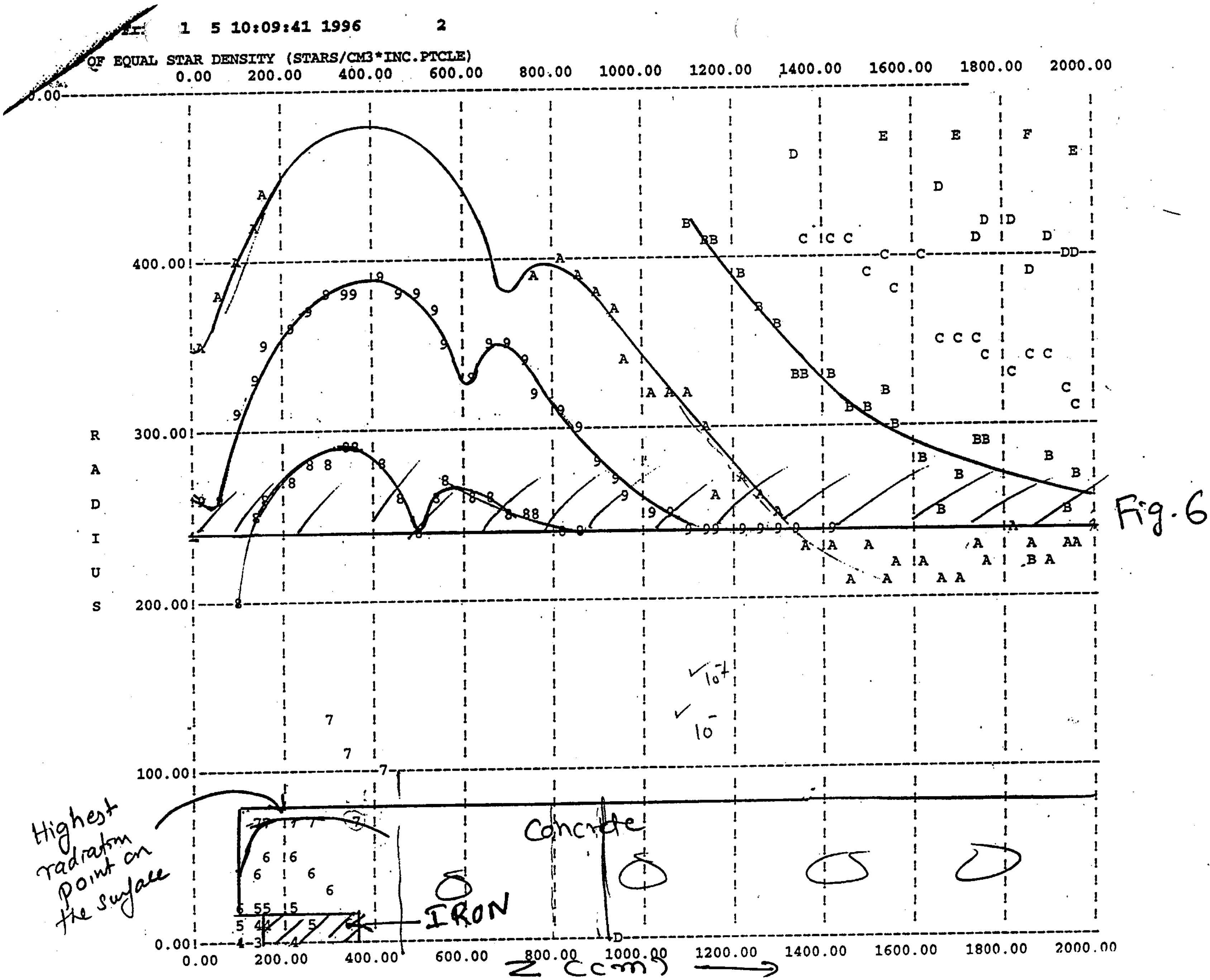


Fig. 6. Monte Carlo calculation using computer code CASIM [3] for interactions of 8 GeV protons with beam absorber design II.

Beam Absorber in the 8 GeV Beam Line

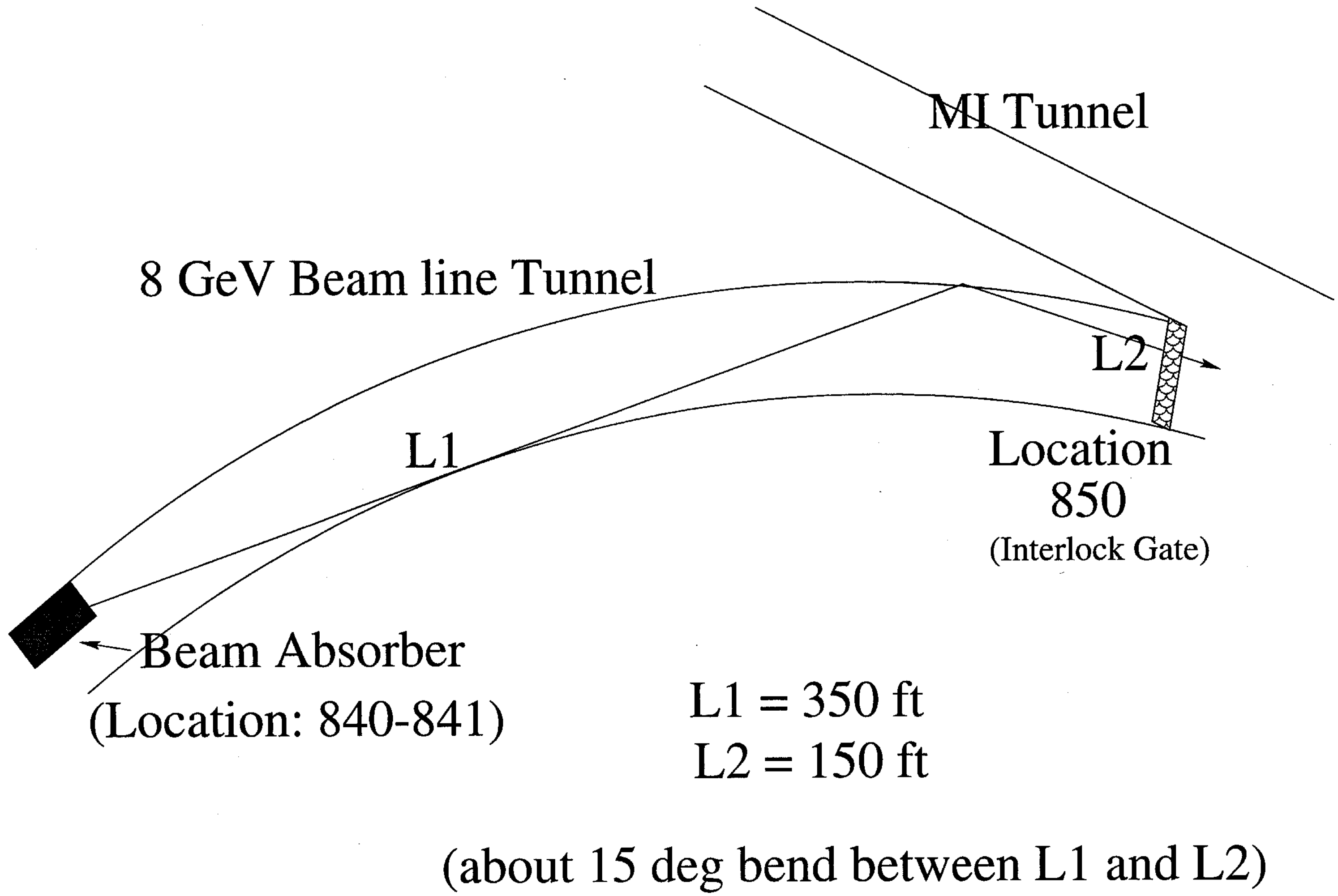


Fig. 7. A schematic view of the 8 GeV beam line tunnel around the location 840 to 850. Location of the interlock gate is also indicated.